A Global Solution for the Gravity Field, Shape, Rotation, and Ephemeris of Eros

Alex Konopliv
M.S. 301-125J
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
E-mail: ask@krait.jpl.nasa.gov
Phone: (818) 354-6105

Additional authors:

Jim Miller, Bill Owen, Don Yeomans, Jon Giorgini
Jet Propulsion Laboratory

Romain Garmier, Jean-Pierre Barriot
CNES

The NEAR-Shoemaker spacecraft was in orbit around 433 Eros for one year from orbit insertion on February 14, 2001 to landing on the asteroid surface on February 12, 2001. As part of the Radio Science investigation, a global gravity solution was generated for Eros using the entire one-year collection of X-band radiometric tracking (Doppler and range) from the Deep Space Network and landmark tracking observations generated from the NEAR spacecraft images of Eros. The initial orbit for NEAR was nearly circular with a radius of about 350 km and an inclination of 35 degrees to the equator of Eros. The orbit of NEAR was progressively lowered as the rotation and gravity field of Eros became better known. The best orbit for determination of the gravity field of Eros occurred on July 14, 2000 and lasted for 10 days. This orbit was polar and circular with a radius of 35 km and provides a very strong data set for the gravity field. The entire remaining mission outside these ten days gives only a slight improvement in the gravity field.

The gravity field of Eros was modeled with both spherical harmonics and ellipsoidal harmonics. Spherical harmonics are not an ideal representation for the irregularly shaped Eros (~17x6x6 km) since they are known to converge only outside the smallest sphere enclosing the body. So they were not used for the landing on the surface of Eros. However, since the NEAR orbit always remained outside the surrounding sphere, spherical harmonics provide a simple straightforward solution for the Eros gravity field. Together with a spherical harmonic representation of the shape of Eros, it is possible to gain some insights about the interior of Eros. The ellipsoidal harmonics, likewise, are known to converge only outside the smallest triaxial ellipsoid that encloses Eros and in general can be mapped closer to the surface than spherical harmonics for most of the body. Both methods generate comparable solutions that imply the same conclusions about the density distribution of Eros. The spherical harmonic global gravity field is determined to degree 10 or about 5-km half-wavelength resolution. At this degree, the signal (or rms magnitude of the coefficients) equals the noise (or rms magnitude of the coefficient uncertainties).

The shape of Eros was determined using the NEAR Laser Ranging (NLR) data. Since the orbits of the NEAR spacecraft are well determined, the shape can be determined independently of the orbits. Using a least-squares algorithm, a 120th degree and order spherical harmonic solution of Eros was determined. This solution is consistent with the gravity field in that the same orientation for Eros is used (pole and rotation rate). If there is an offset between the pole used for the gravity field and the one used for the shape, errors are introduced into the comparison between the shape and gravity models. The purpose of this solution is to provide an accurate long wavelength spherical harmonic representation of Eros for comparison with the gravity field. The resulting residual RMS of the shape model varies between 20 and 60 meters depending on the data arc. The actual data accuracy is closer to one meter, and indicates that the short wavelength aspect of this shape model could be improved.

As the result of the landmark observations, the orbits of NEAR are very well determined and the NLR data can be processed independently. The landmarks are very important for the higher altitude orbits. For the initial 350-km circular orbit, for example, the landmark tracking lowers the overall orbit error to tens of meters, whereas the orbit error with radiometric tracking alone is about 20 km. The orbit error for the close orbits (35-km) is several meters in all three directions and for the most part can be obtained with sufficient radiometric tracking alone. However, the landmark tracking reduces the time required to redetermine the spacecraft position after a maneuver.

The comparison of the gravity and shape models indicates a fairly uniform Eros. The offset between the center-of-mass and center-of-figure from the gravity and shape models is about 30 meters in the Z direction and less in the other directions. With the overall length of Eros of 35-km, this indicates long wavelength density variations of about 1%. The differences of the gravity field and a gravity field from a constant density shape model are measurable to degree 7. The differences are only detectable for the ends of Eros and are about 1% of the gravity magnitude. The Bouguer gravity (measured gravity minus gravity from shape) shows a mass deficiency at the ends of about 3 milligals when mapped to a 16-km sphere. This may be partly explained by a less dense regolith of about 100 meters or a slight increase of mass (5%) near the asteroid center. The uncertainty of the Bouguer gravity is about one milligal and is dominated by uncertainties in the shape model.

The ephemeris of Eros is also very accurately determined from the ranging data to the NEAR spacecraft. With the accurately determined NEAR orbits about Eros, the range measures the center-of-mass of Eros in the Earth line-of-sight direction to several meters. The most significant perturbation on the Eros orbit other than the Sun is a 0.4 AU flyby of the asteroid Vesta in July 2000. This allows for an estimate of the mass of Vesta to be 18.2 $\pm$ 0.4 km^3/s^2. This is consistent with the Vesta estimate of Standish of 17.8 $\pm$ 0.2 from the effect of Vesta on the Mars orbit. A third independent estimate of the Vesta GM from closeVesta flybys of the asteroid Arete also confirms the 17.8 GM value of Vesta.